What is claimed is:

1. A method for determining vector mismatch between a plurality of signal paths in a signal processing system, the method comprising:

(a) providing a periodic calibration signal having a plurality of tones;

(b) frequency translating the calibration signal using the signal processing system to provide a first set of observed samples;

(c) comparing the first sample set to a second set of samples modeled by a function of parameters including an estimated vector mismatch and a plurality of basis functions; and

(d) determining, at least to an estimate, a value of vector mismatch that minimizes the difference between the first sample set and the second sample set.

2. The method of claim 1 wherein:

(a) the signal paths include an in-phase signal path and a quadrature signal path; and

(b) vector mismatch includes deviation from a quadrature relationship between the in-phase signal path and the quadrature signal path.

3. The method of claim 1 wherein:

(a) the signal paths include a plurality of signal paths coupled to respective elements of a spatially selective array; and

(b) vector mismatch includes deviations from a predetermined phase and amplitude relationship between each respective one of the plurality of signal paths, the deviations degrading spatial selectivity of the array.

4. The method of claim 3 further comprising transmitting the calibration signal through an antenna placed at a fixed position with respect to the array elements.

5. The method of claim 1 wherein the number of samples in the sample set is significantly greater than the number of parameters of the function, whereby the function is overdetermined.

6. The method of claim 1 further comprising:

(a) providing a plurality of first sample sets;

(b) comparing each first sample set to a respective second sample set of samples modeled as a function of parameters including an estimated vector mismatch, and a plurality of basis functions;

(c) determining, at least to an estimate, a value of vector mismatch that minimizes the difference between each first sample set and each respective second sample set; and

(d) statistically combining the values of vector mismatch determined for each one of the plurality of first sample sets.

7. The method of claim 1 wherein the determined vector mismatch includes a first value representative of phase mismatch and a second value representative of gain mismatch, the values being representative of mismatches between the signal paths.

8. The method of claim 7 wherein:

(a) the determined vector mismatch includes a plurality of phase and gain mismatch values;

(b) the plurality of values includes a phase and gain mismatch value for each one of the plurality of tones; and

(c) each one of the plurality of values is representative of vector mismatch between the signal paths from frequency translation of one of the plurality of tones.

9. The method of claim 1 wherein the parameters further include a parameter indicative of at least one environmental condition.

10. The method of claim 9 wherein the environmental condition is a temperature.

11. The method of claim 9 wherein the environmental condition is a local oscillator frequency.

12. The method of claim 1 wherein each one of the plurality of basis functions forms an orthogonal basis for each one of the plurality of tones.

13. The method of claim 1 wherein:

(a) the plurality of basis functions includes a first function set and a second function set; and

(b) one basis function of the first function set and one basis function of the second function set together form an orthogonal basis for each one of the plurality of tones.

14. The method of claim 13 wherein:

(a) each one of the plurality of basis functions is sinusoidal and periodic at a frequency equal to the frequency of the tone whose orthogonal basis is formed thereby; and

(b) each basis function of the first function set is displaced from each basis function of the second function set by a predetermined phase offset to establish a predetermined vector relationship therebetween.

15. The method of claim 1 wherein the value of vector mismatch that minimizes the difference between the first sample set and the second sample set is determined byrecursive least mean squares.

16. The method of claim 15 wherein the values determined by least mean squares are constrained to a predetermined bounded region.

17. The method of claim 1 wherein the value of vector mismatch that minimizes the difference between the first sample set and the second sample set is determined by recursive least squares with an exponential forgetting window.

18. The method of claim 1 wherein:

(a) the function is a linear product of

(1) a matrix of results of the basis functions; and

(2) a parameter vector of variables representative of the vector mismatch; and

(b) the value of vector mismatch that minimizes the difference between the first sample set and the second sample set is determined by linear regression estimation of the parameter vector.

19. The method of claim 18 wherein **X** is the matrix, **Y** is the observation vector, **Z** is the parameter vector, and the linear regression estimation is determined according to the formula:

$$Z = (X^T X)^{-1} X^T Y$$

20. A method in accordance with claim 1 for reducing vector mismatch between signal paths in a signal processing system, the method further comprising applying at least one of a phase adjustment and a gain adjustment to at least one of the signal paths.

21. The method of claim 20 further comprising:

(a) computing complex exponentials corresponding to the vector mismatch; and

(b) based on the complex exponentials, deriving coefficients of impulse response that is inversely representative of the vector mismatch; and

(c) realizing the impulse response in a digital filter to apply the adjustment.

22. The method of claim 21 wherein the coefficients are derived by applying the complex exponentials to appropriate frequency bands of an inverse fast Fourier transform.

23. The method of claim 21 wherein the digital filter is a finite-impulse-response filter.

24. The method of claim 20 further comprising repeatedly determining vector mismatch and applying a phase and gain adjustment, inverse of the determined vector mismatch, to reduce the vector mismatch.

25. A signal processing system having an in-phase signal path and a quadrature signal path and including a vector mismatch determination system comprising:

(a) a calibration signal subsystem that, during operation, provides a periodic calibration signal having a plurality of tones;

(b) a sample modeling and mismatch determination subsystem responsive to the calibration signal to provide a plurality of first sets of observed samples and determine vector mismatch between the plurality of signal paths, vector mismatch including deviation from a quadrature relationship between the in-phase signal path and the quadrature signal path, wherein, during operation:

(1) each first sample set is compared to a respective second set of samples modeled by a linear product of a parameter vector of variables representative of an estimated vector mismatch and a matrix of results from a plurality of basis functions, the estimated vector mismatch including a plurality of values representative of phase mismatch and a plurality of values representative of gain mismatch at each one of the plurality of tones;

(2) a value of vector mismatch is determined, at least to an estimate, that minimizes the difference between the first sample set and the second sample set, the determination being made by a bounded least mean squares algorithm;

(3) the number of samples in the sample set is significantly greater than the number of parameters of the function, whereby the function is overdetermined;

(4) the values of vector mismatch determined for each one of the plurality of first sample sets are statistically combined;

(5) the plurality of basis functions includes a first function set and a second function set, one basis function of the first function set and one basis function of the second function set together forming an orthogonal basis for each one of the plurality of tones;

(6) each one of the plurality of basis functions is sinusoidal and periodic at a frequency equal to the frequency of the tone whose orthogonal basis is formed thereby; and

(7) each basis function of the first function set is displaced from each basis function of the second function set by a predetermined phase offset to establish a predetermined vector relationship therebetween.

26. A system in accordance with claim 25 for reducing vector mismatch between quadrature signal paths in a signal processing system, wherein, during operation at least one of a phase adjustment and a gain adjustment is repeatedly determined and applied to at least one of the signal paths, the system further comprising:

(a) a correction coefficient generator responsive to the determined value of vector mismatch to compute complex exponentials corresponding to the vector mismatch;

(b) a coefficient generator responsive to the complex exponentials to derive coefficients of an impulse response that is inversely representative of the vector mismatch, the coefficients being derived by applying the complex exponentials to appropriate frequency bands of an inverse fast Fourier transform; and

(c) a finite-impulse-response digital filter coupled to the coefficient generator to realize the impulse response and apply the adjustment.

27. A signal processing system comprising:

(a) means for providing a periodic calibration signal having a plurality of tones;

(b) means for frequency translating the calibration signal to provide a first set of observed samples;

(c) means for comparing the first sample set to a second set of samples modeled by a function of parameters including an estimated vector mismatch and a plurality of basis functions; and

(d) means for determining, at least to an estimate, a value of vector mismatch that minimizes the difference between the first sample set and the second sample set.

28. A method for correcting vector mismatch between a plurality of signal paths in a signal processing system, the method comprising:

(a) providing a periodic calibration signal;

(b) frequency translating the calibration signal using the signal processing system to provide first and second sets of observed samples, wherein:

(1) the samples of the first sample set are derived from a first signal path; and

(2) the samples of the second sample set are derived from a second signal path through an adaptive filter having a set of adaptable coefficients; and

(c) adapting the coefficients to minimize the difference between the first sample set and the second sample set.

~~29. The method of claim 28 wherein the periodic calibration signal~~ includes a plurality of tones.

30. The method of claim 28 wherein adapting is performed by a least mean squares algorithm.

31. The method of claim 30 wherein the values determined by least mean squares are constrained to a predetermined bounded region.

32. A signal processing system having a plurality of signal paths and including a vector mismatch correction system comprising:

(a) a calibration signal subsystem that, during operation, provides a periodic calibration signal that includes a plurality of tones; and

(b) a digital subsystem responsive to the calibration signal to provide first and second sets of observed samples derived from first and second ones of the signal paths, wherein, during operation:

(1) the second sample set is derived through an adaptive filter having a set of adaptable coefficients; and

(2) the coefficients are adapted by a bounded least mean squares algorithm to minimize the difference between the first sample set and the second sample set.

33. Apparatus for correcting vector mismatch between a plurality of signal paths in a signal processing system, the apparatus comprising:

(a) means for providing a periodic calibration signal;

(b) means for frequency translating the calibration signal using the signal processing system to provide first and second sets of observed samples, wherein:

(1) the samples of the first sample set are derived from a first signal path; and

(2) the samples of the second sample set are derived from a second signal path through an adaptive filter having a set of adaptable coefficients; and

(c) means for adapting the coefficients to minimize the difference between the first sample set ~~and the second~~ sample set.

34. A method for generating a phase-synchronous calibration signal, the method comprising:

(a) generating a local oscillator signal;

(b) generating a baseband calibration signal;

(c) coupling the local oscillator signal and the baseband calibration signal to a mixer to provide a radio frequency calibration signal thereby; and

(d) coupling the radio frequency calibration signal to one or more mixers that, during operation, translate the radio frequency calibration signal, using the local oscillator signal, to at least one baseband calibration signal.

35. ~~The method of claim 34 further comprising:~~

(a) providing a plurality of array elements responsive to radio frequency electromagnetic signals; and

(b) transmitting the radio frequency calibration signal through an antenna placed at a fixed position with respect to the array elements, wherein the radio frequency calibration signal is coupled to each mixer through the respective array elements.

36. The method of claim 34 wherein the local oscillator signal and baseband calibration signal are derived from a high frequency output of a high-stability master oscillator.

37. The method of claim 34 further comprising:

(a) providing a phase adjustor between the local oscillator and the mixer; and

(b) adjusting the phase of the local oscillator signal at the second mixer to optimize the amplitude of the baseband calibration signal.

38. The method of claim 37 wherein:

(a) the frequency translation subsystem translates the radio frequency calibration signal to an in-phase baseband calibration signal and a quadrature baseband calibration signal; and

(b) the phase of the local oscillator signal at the second mixer is adjusted to balance the amplitudes of the in-phase baseband calibration signal and the quadrature baseband calibration signal.

39. Apparatus for providing a phase-synchronous calibration signal, the apparatus comprising:

(a) a high-stability master oscillator that, during operation, generates a high frequency clock signal;

(b) a frequency translation subsystem including:

(1) a local oscillator responsive to the high frequency clock signal to generate a local oscillator signal;

(2) a first mixer responsive to the local oscillator signal and the amplified radio frequency input signal to generate a first reduced frequency signal; and

(3) a second mixer responsive to the local oscillator signal and the amplified radio frequency input signal to generate a second reduced frequency signal;

(c) a calibration signal subsystem including:

(1) a baseband calibration signal generator responsive to the high frequency clock signal to generate a baseband calibration signal having one or more frequency components within the frequency range of the reduced frequency signal; and

(2) a third mixer responsive to the local oscillator signal and the baseband calibration signal to provide a radio frequency calibration signal, the second mixer being coupled to the frequency translation subsystem such that the radio frequency calibration signal can be injected therein; and

(d) a phase adjustor between the local oscillator and the third mixer, whereby the phase of the local oscillator signal can be adjusted at the third mixer to balance the amplitudes of the first and second reduced frequency signals.

40. Apparatus for generating a phase-synchronous calibration signal, the apparatus comprising:

(a) means for generating a local oscillator signal;

(b) means for generating a baseband calibration signal;

(c) means for frequency translating the baseband calibration signal using the local oscillator signal to provide a radio frequency calibration signal; and

(d) means for frequency translating the radio frequency calibration signal using the local oscillator signal to at least one ~~baseband calibration signal.~~

41. A method for providing a calibration signal having a plurality of tones, the method comprising:

(a) generating a sequence of digital values at a predetermined sample rate; and

(b) converting the digital values into analog values to generate a baseband calibration signal, the calibration signal including one or more tones;

(c) generating a local oscillator signal; and

(d) mixing the local oscillator signal and the baseband calibration signal to provide a radio frequency calibration signal.

42. The ~~method of claim 41 wherein the calibration~~ signal further includ~~es one or~~ more aliases of at least one of the tones.

43. The method of claim 41 further comprising:

(a) translating the radio frequency calibration signal to one or more reduced frequency calibration signals; and

(b) filtering each reduced frequency calibration signal to remove undesired tones, the undesired tones falling outside a frequency range of interest.

44. The method of claim 43 wherein filtering is performed by a digital filter having deep but narrow spectral nulls at the frequencies of the undesired tones.

45. The method of claim 41 wherein the sequence of digital values consists of two digital values and the calibration signal includes a tone having a frequency of one half the predetermined sample rate.

46. The method of claim 41 wherein converting the digital values into analog values includes providing a plurality of preset multipliers, each digital value corresponding to one of the multipliers.

47. The method of claim 46 wherein:

(a) the sequence of digital values includes one or more pairs of values having the same magnitude but opposite sign; and

(b) each of the pairs of values corresponds to one of the multipliers.

48. Apparatus for providing a calibration signal having a plurality of tones, the apparatus comprising:

(a) a square wave oscillator that, during operation, generates a baseband calibration signal including a fundamental tone and a plurality of harmonic tones at odd-numbered multiples of the fundamental tone frequency;

(b) a local oscillator that, during operation, generates a local oscillator signal;

(c) a mixer responsive to the local oscillator signal and the baseband calibration signal to provide a radio frequency calibration signal;

(d) a frequency translation subsystem responsive to the radio frequency calibration signal to provide one or more reduced frequency calibration signals; and

(e) a digital filter coupled to the frequency translation subsystem, the filter having deep but narrow spectral nulls at the frequencies of tones of the calibration signal outside a frequency range of interest.

49. Apparatus for providing a calibration signal having a plurality of tones, the apparatus comprising:

(a) means for generating a sequence of digital values at a predetermined sample rate;

(b) means for converting the digital values into analog values to generate a baseband calibration signal, the calibration signal including one or more tones;

(c) means for generating a local oscillator signal; and

(d) means for mixing the local oscillator signal and the baseband calibration signal ~~to provide a radio frequency calibration signal~~.

50. A method for determining vector mismatch between a plurality of signal paths in a signal processing system that includes a digital signal processor, the method comprising:

(a) providing a periodic calibration signal;

(b) frequency translating the calibration signal using the signal processing system to provide a plurality of first sets of observed samples;

(c) when processing time of the digital signal processor is available, performing a vector mismatch calibration process based on one of the first sample set, the process including:

(1) comparing the first sample set to a respective second sample set of samples modeled as a function of parameters including an estimated vector mismatch and a plurality of basis functions; and

(2) determining, at least to an estimate, a value of vector mismatch that minimizes the difference between each first sample set and each respective second sample set; and

(d) statistically combining the values of vector mismatch determined for each one of the plurality of first sample sets.

51. Apparatus for determining vector mismatch between a plurality of signal paths in a signal processing system that includes a digital signal processor, the apparatus comprising:

(a) means for providing a periodic calibration signal;

(b) means for frequency translating the calibration signal to provide a plurality of first sets of observed samples;

(c) means for determining when processing time of the digital signal processor is available and, during available processing time, performing a vector mismatch calibration process based on one of the first sample set, the process including:

(1) comparing the first sample set to a respective second sample set of samples modeled as a function of parameters including an estimated vector mismatch and a plurality of basis functions; and

(2) determining, at least to an estimate, a value of vector mismatch that minimizes the difference between each first sample set and each respective second sample set; and

(d) means for statistically combining ~~the values of~~ vector mismatch determined for each ~~one~~ of the plurality of first sample sets.